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DEFENCE R&D DÉFENSE

WaMoS II, CFAV Quest Trial Q279

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Contract Number: W7707-03-2236

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14. ABSTRACT
This report details some of the wave data comparisons between an operational WaMoS II wave radar mounted on the CFAV QUEST and a free floating TRIAXYS directional wave buoy. The data were taken from a trial in late January/ early February 2004 off the Scotian Shelf in deep water. In general the comparisons between the two measuring devices was very good. If one takes the measurement parameters of significant wave height and peak period as indicators of sea state then the two devices showed excellent agreement in most conditions. If the sea surface is truly homogenous and the buoy location is in the same area as that measured by WaMoS II, then one might expect similar results for all measured parameters and spectra. By and large these were the findings of this report. However, there is a significant difference in what each device is measuring. Typically, with the Quest travelling at 6 knots, over a 30 minute averaging period, the WaMoS II samples approximately 7 sq km of the ocean surface. The WaMoS II data thus incorporates a large spatial average. On the other hand the TRIAXYS directional wave buoy is measuring data from a single point (with some drift over the 30 minute period). Even in deep water, the sea surface is not uniform either spatially or temporally,so we would expect to see some differences in the data between the two sensors. Most noticeable were the differences in the overall shape of the 1-dimensional frequency spectra and the 2-dimensional frequency/direction spectra in some instances.

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Abstract

This report details some of the wave data comparisons between an operational WaMoS II wave radar mounted on the CFAV QUEST and a free floating TRIAXYS directional wave buoy. The data were taken from a trial in late January/ early February 2004 off the Scotian Shelf in deep water. In general the comparisons between the two measuring devices was very good. If one takes the measurement parameters of significant wave height and peak period as indicators of sea state then the two devices showed excellent agreement in most conditions. If the sea surface is truly homogenous and the buoy location is in the same area as that measured by WaMoS II, then one might expect similar results for all measured parameters and spectra. By and large these were the findings of this report. However, there is a significant difference in what each device is measuring. Typically, with the Quest travelling at 6 knots, over a 30 minute averaging period, the WaMoS II samples approximately 7 sq km of the ocean surface. The WaMoS II data thus incorporates a large spatial average. On the other hand the TRIAXYS directional wave buoy is measuring data from a single point (with some drift over the 30 minute period). Even in deep water, the sea surface is not uniform either spatially or temporally,so we would expect to see some differences in the data between the two sensors. Most noticeable were the differences in the overall shape of the 1-dimensional frequency spectra and the 2-dimensional frequency/direction spectra in some instances.

Résumé

Le présent rapport décrit certaines comparaisons entre les données relatives à la houle obtenues avec un radar opérationnel WaMoS II d'étude de la houle monté sur le NAFC QUEST et les données obtenues avec une bouée directionnelle libre TRIAXYS d'étude de la houle. Les données ont été recueillies au cours d'un essai mené à la fin de janvier et au début de février 2004 au large de la plate-forme néo-écossaise, en eau profonde. En général, les comparaisons ont montré une très bonne concordance des données des deux systèmes de mesure. Si on considère comme paramètres de mesure indicateurs de l'état de la mer la hauteur significative de la houle et la période de crête, on obtient une excellente concordance des deux systèmes dans la plupart des conditions. Lorsque la surface de la mer est vraiment homogène et que la bouée est placée dans la même zone de mesure que le WaMoS II, on peut s'attendre à obtenir des résultats similaires pour tous les paramètres et spectres mesurés. Dans l'ensemble, c'est ce que confirme le présent rapport. Cependant, il existe une différence importante quant aux mesures effectuées par chaque système. Normalement, lorsque le Quest se déplace à une vitesse de 6 nuds, sur une

période d’établissement de la moyenne de 30 minutes, le WaMoS II recueille des échantillons sur approximativement 7 km2 de surface océanique. Les données du WaMoS II comportent par conséquent une moyenne spatiale élevée. D’autre part, la bouée directionnelle TRIAXYS d’étude de la houle recueille des données à partir d’un seul point (avec une certaine dérive sur la période de 30 minutes). Même en zone d’eau profonde, la surface de la mer n’est pas uniforme, tant du point de vue spatial que du point de vue temporel, de sorte qu’on peut s’attendre à observer certaines différences entre les données fournies par les deux systèmes. Dans certains cas, les différences de forme générale des spectres de fréquences unidimensionnels et des spectres de fréquences/directions bidimensionnels étaient très nettes.

Executive summary

Background

The purpose of the CFAV QUEST sea trial Q279 was to collect wave measurements with a number of shipboard devices, while conducting 30-minute long runs at various speeds and headings into the waves, in the vicinity of a drifting directional wave buoy. Shipboard measurements included two wave radars, a TSK over-the-bow wave elevation sensor, and a ship motion package. These data are to be used to develop a system to obtain accurate directional wave spectra and wave statistics from a shipboard measurement system through fusion of data from a number of measurement devices. This contractor report considers only the comparison of one of the wave radars and the wave buoy data. Analysis of other trial data is underway and will be reported in a future DRDC Atlantic Technical Memorandum.

Principal results

Data from the Quest sea trial has demonstrated that state-of-the art wave radar processors, once calibrated to a given navigational radar and ship/radar antenna geometry, can provide accurate directional wave spectra and wave statistics in a variety of seaway conditions.

Significance of results

Older generation wave radars could provide reasonable directional and frequency information but not very accurate wave height data. Since the latest generation wave radars seem to provide improved height predictions as well, it should be possible to provide a shipboard system, perhaps fusing wave radar data with ship motion data to improve accuracy in some conditions. These systems can provide an important input to long-term structural health monitoring and provide input to ship operator guidance systems. Example guidance systems where shipboard wave measurement would be beneficial include a guidance system for helicopter operations and a slam warning system (now under consideration for the KINGSTON class).

Future work

Work is underway to examine other data from the sea trial to assess the performance of various shipboard measurement devices, under various seaway and ship operating conditions. This analysis will be used to determine the best means of achieving accurate wave measurements from shipboard systems under as wide a variety of conditions as possible.

Sea-Image Communications Ltd., OceanWaveS GmbH; 2004;
WaMoS II, CFAV Quest Trial Q279; DRDC Atlantic CR 2004-141;
Defence R & D Canada – Atlantic.

Sommaire

Contexte

L’essai en mer Q279 mené à bord du NAFC QUEST visait à recueillir des données relatives à la houle à l’aide d’un certain nombre de systèmes embarqués, en exécutant des parcours d’une durée de 30 minutes à différentes vitesses et différents caps dans la houle, dans le voisinage d’une bouée directionnelle dérivante d’étude de la houle. Pour effectuer les mesures à partir du navire, on a utilisé deux radars d’étude de la houle, un capteur de hauteur de houle TSK passé par dessus la proue et une suite de capteurs des mouvements du navire. Les données doivent tre utilisées pour mettre au point, à partir d’un système de mesure embarqué, un nouveau système qui permettra d’obtenir des spectres directionnels de houle et des statistiques de houle de précision par la fusion des données d’un certain nombre d’appareils de mesure. Le présent rapport d’entrepreneur traite uniquement de la comparaison entre les données d’un des radars d’étude de la houle et les données de la bouée d’étude de la houle. On procède actuellement à l’analyse d’autres données d’essai et on en présentera les résultats dans un futur document technique de RDDC Atlantique.

Résultats principaux

Les données de l’essai effectué en mer à bord du Quest ont montré que les processeurs de radar ultra-modernes d’étude de la houle, une fois étalonnés en fonction d’une géométrie donnée de radar de navigation et d’antenne de navire/radar, peuvent fournir des spectres directionnels de houle et des statistiques de houle de précision dans une variété de conditions de voies maritimes.

Portée des résultats

Les radars d’étude de la houle des générations antérieures pouvaient fournir des données de direction et de fréquence de qualité raisonnable, mais leurs données relatives à la hauteur de la houle n’étaient pas très précises. Comme les radars d’étude de la houle de dernière génération semblent présenter une amélioration sur le plan de la prévision de la hauteur également, il devrait tre possible, en fusionnant les données de radars d’étude de la houle et les données de capteurs des mouvements des navires, de mettre au point un système embarqué offrant une plus grande précision dans certaines conditions. Un tel système pourrait jouer un rôle important dans la surveillance de l’état des structures à long terme et aider les systèmes de guidage utilisés par les exploitants de navires. Un système de guidage pour les opérations des hélicoptères et un système d’avertissement de tossage (dont on envisage doter les navires de la classe KINGSTON), par exemple, bénéficieraient de l’apport d’un système de mesure de houle embarqué.

Recherches futures

On examine actuellement d’autres données de l’essai en mer dans le but d’évaluer les performances de divers systèmes de mesure embarqués, dans différentes conditions de voies maritimes et d’exploitation des navires. Cette analyse servira à déterminer la meilleure façon d’obtenir des mesures de houle précises à partir de systèmes embarqués dans la plus grande variété possible de conditions.

Sea-Image Communications Ltd., OceanWaveS GmbH; 2004; Essai Q279 mené avec le WaMoS II à bord du NAFC Quest;
DRDC Atlantic CR 2004-141; R & D pour la défense Canada – Atlantique.

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WaMoS II

CFAV Quest Trial Q279

May 10, 2004

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Nomenclature

Symbol	Unit	Parameter
Hs	m	Significant wave height
Tp	s	Peak wave period
θp	° True	Peak wave direction (coming from)
λp	m	Peak wave length
QI	-	WaMoS II quality index
$E(f,\theta)$	m^2/(Hz rad)	Frequency direction spectrum
S(f)	m^2/(Hz rad)	Frequency spectrum

Acknowledgement

The data from the TRIAXYS™ wave buoy and the CFAV Quest were kindly provided by Dr. Dave Stredulinsky, Defence R&D Canada (DRDC), Halifax, Nova Scotia, Canada.

1. Introduction

From January 22, 2004 to February 6, 2004 a WaMoS II wave radar system was installed on board the Canadian Forces Auxiliary Vessel Quest (CFAV Quest) to carry out a trial comparing its performance with several other types of wave measuring devices. The trial was conducted in the area of the Scotian Shelf off of the coast of Nova Scotia, Canada.

The Defence R&D Canada (DRDC) Atlantic's research ship (Fig. 1) is specifically designed for open ocean research. The Quest conducts 7 to 10 trials per year in a wide range of R&D activities, from research on the acoustic properties of the ocean to experiments on ship signatures and safety.

Fig. 1: Picture of the research ship CFAV Quest

In this report, data from the WaMoS II wave radar is compared with data from a directional wave buoy (TRIAXYS™, DRDC). During the trials the TRIAXYS™ wave buoy was not tethered and was picked up and redeployed each day of the trials. The GPS on the buoy recorded its position.

2. The Trial

The duration of trial Q279 starting at Halifax, Canada, was from January 26, 2004, 14:36 UTC until February 5, 2004, 21:51 UTC. All time references in this report will be stated in Greenwich Mean Time (UTC). The CFAV Quest sailed from Halifax 120 to 150 miles southwards to compare the performance of the WaMoS II wave monitoring system with a TRIAXYS™ wave buoy in deep water. In Fig. 2 the blue lines indicate the position of the CFAV Quest during the trial, and the green lines the position of the wave buoy. The red dots indicate the position of the CFAV Quest at specific times.

For each run, the wave buoy was deployed in a free floating mode and the CFAV Quest sailed past the buoy on three different course headings, and at different speeds. The buoy was used as an independent wave sensor for comparisons with WaMoS II. The reference buoy data was available from January 27, 2004, 13:59 until February 4, 2004, 19:26. In addition to the buoy data, wave data from a Miros Wavex system, and a ship borne TSK was captured. TSK data is only available after February 3, 2004. The wave heights from all available wave sensors were recorded on an hourly basis.

From February 1, 21:58 to February 2, 18:53 the CFAV Quest interrupted the cruise to return to Halifax.

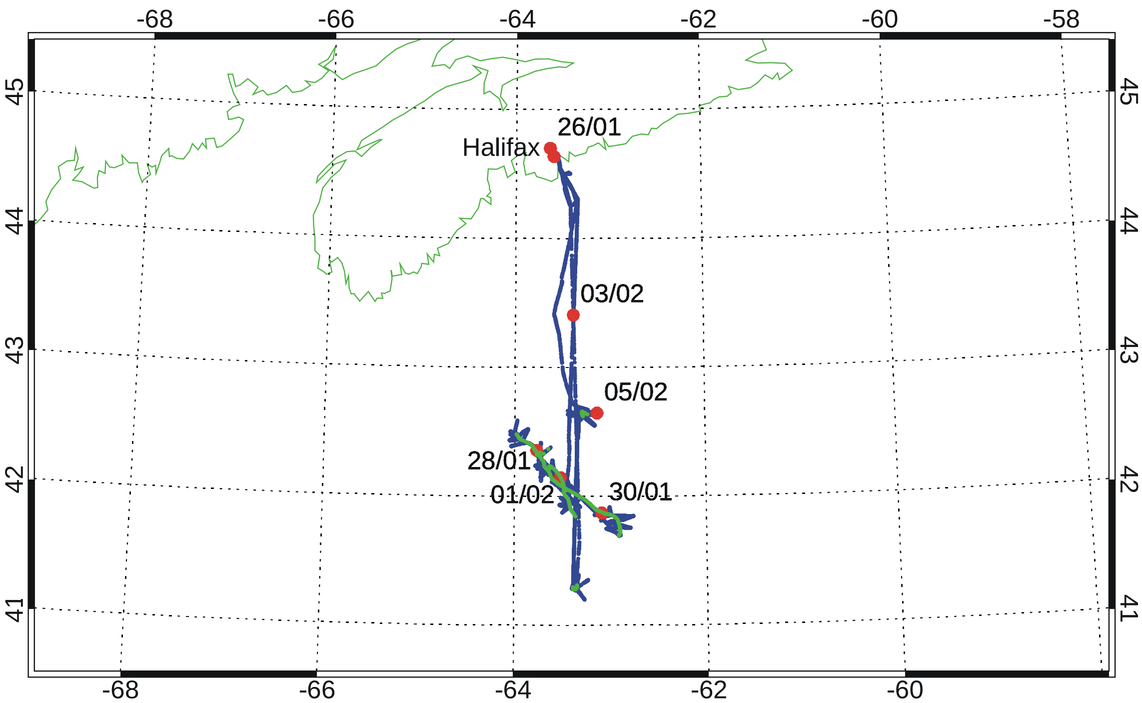

Fig. 2: Map with positions of WaMoS II measurements taken onboard the CFAV Quest between January 26 to February 5, 2004.

2.1. WaMoS II Installation Parameters

The WaMoS II was connected to a Decca BridgeMaster II 340 X-Band radar. The radar related WaMoS II system parameters are given in Table 1.

Table 1: WaMoS II system parameter for CFAV Quest

WaMoS II Station	**CFAV Quest**	
Radar repetition rate	Δt	2.48 s
Maximum Frequency	$Fmax = 1 / \Delta t$	0.4 Hz
WaMoS II sampling rate	Fs	20 MHz
Spatial resolution	Δx	7.5 m
Minimum range	R_{min}	240 m
Maximum range	R_{max}	2160 m
Number of images	Ni	32
Size of Wave analysis area	$128*256*\Delta x^2$	1.8 km^2
Number of analysis areas	N_{box}	3
Frequency resolution	$\Delta f = 1 / (Ni\Delta t)$	0.0126 Hz

The WaMoS II wave analysis areas were set in three different directions (120°, 180° and 240° relative to the stern of the ship) within a distance of 590 m to 1550 m from the radar antenna (see Fig. 3).

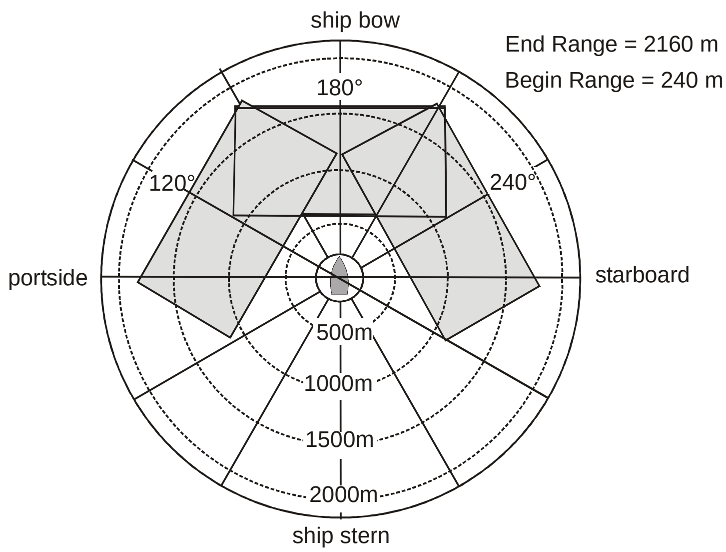

Fig. 3: Sketch of the position and alignment of the WaMoS II wave analysis areas (grey).

The wave analysis is carried out for all of these three window positions in order to guarantee full directional information. The resulting spectra are averaged (spatial averaging). From these spectra the sea state parameters are derived. To obtain results that are comparable with the buoy data, a running average over 30 min is created (temporal averaging).

3. Available Data Sets

3.1. WaMoS II Data

WaMoS II data were collected from January 26, 2004, 14:36 to February 5, 2004, 21:51. The data are sampled continuously with sequences of thirty-two digital radar images taken from the sea surface. Thirty-two images per sequence yields a frequency resolution of $\Delta f = 0.0126$ Hz.

Fig. 4 shows a nautical radar image captured on January 30, 2004, 18:59. At this time the vessel is moving at 5.7 knots, in an easterly direction (91° True). The plot clearly shows the surface waves which can be seen as lines. This so called 'sea clutter' is the raw data that is further analysed to determine the relevant wave information.

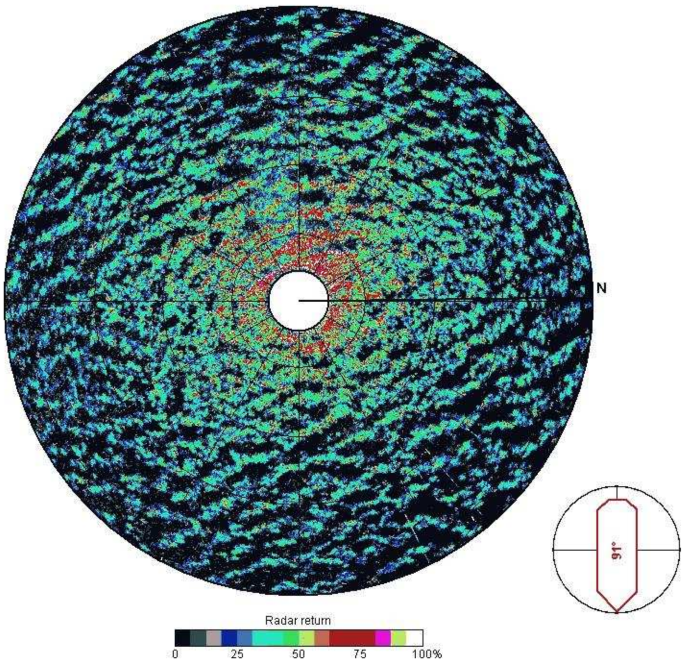

Fig. 4: Nautical radar image as obtained by WaMoS II onboard CFAV Quest, January 30, 2004, 18:59 . The colour coding corresponds to the radar back scatter strength where black indicates no return and white maximum return. The ship course is indicated by the ship bow arrow (bottom right).

3.2. Buoy data

The wave buoy data set (DRDC) is available for the time period from January 27, 2004, 13:59 to February 4, 2004, 19:26. The data include the standard wave parameters of significant wave height (Hs), peak wave period (Tp) and mean magnetic wave direction (θm). The wave direction is corrected for magnetic variation (18.4° W). The data are 30 minute average values. Note that the wave buoy files are named with respect to the beginning of the measurement period, while the WaMoS II files are named with respect to the end of the measurement period.

4. Data Comparison

The WaMoS II raw data are analysed with the standard WaMoS II software. This software delivers the 2-dimensional wave spectrum from which all spectral wave parameters, such as significant wave height (*Hs*), peak wave period (*Tp*) and peak wave direction (θp) are derived.

4.1. Spectral Wave Parameters

In Fig. 5, the time series of *Hs*, *Tp,* θm are shown. The red and yellow dots correspond to the WaMoS II measurements and the blue dots represent the wave buoy data. Both data sets represent 30 minute mean values.

The WaMoS II wave monitoring system includes an internal quality control algorithm which marks each data set with a quality index (QI). The data are then sorted into different data quality categories. A WaMoS II measurement with the best quality is indicated by QI=0. During times of low wind speed or heavy rain, the radar backscatter from the sea surface may be disturbed affecting the quality of the WaMoS II measurements, leading to values of QI > 0. In the Fig. 5, the WaMoS II data with QI = 0 are depicted in red while data with QI > 0 are marked in yellow.

WaMoS II can not measure waves lower than *Hs* < 0.5 m as the wave signatures in the radar image are too weak to derive accurate sea state information.

For the significant wave height (*Hs*), the WaMoS II measurements and the wave buoy measurements show a good agreement for most of the time. In the marked section, A1 in the upper panel of Fig. 5, some deviations between WaMoS II and the wave buoy can be seen. At this time the data communication between WaMoS II and the Quest's GPS failed. Since ship speed and course are crucial input parameters for ship-borne WaMoS II wave analysis, this caused a loss of quality in the WaMoS II measurements. The internal quality control for these measurements was QI = 900. During this period the WaMoS II *Hs* is lower than that reported by the buoy.

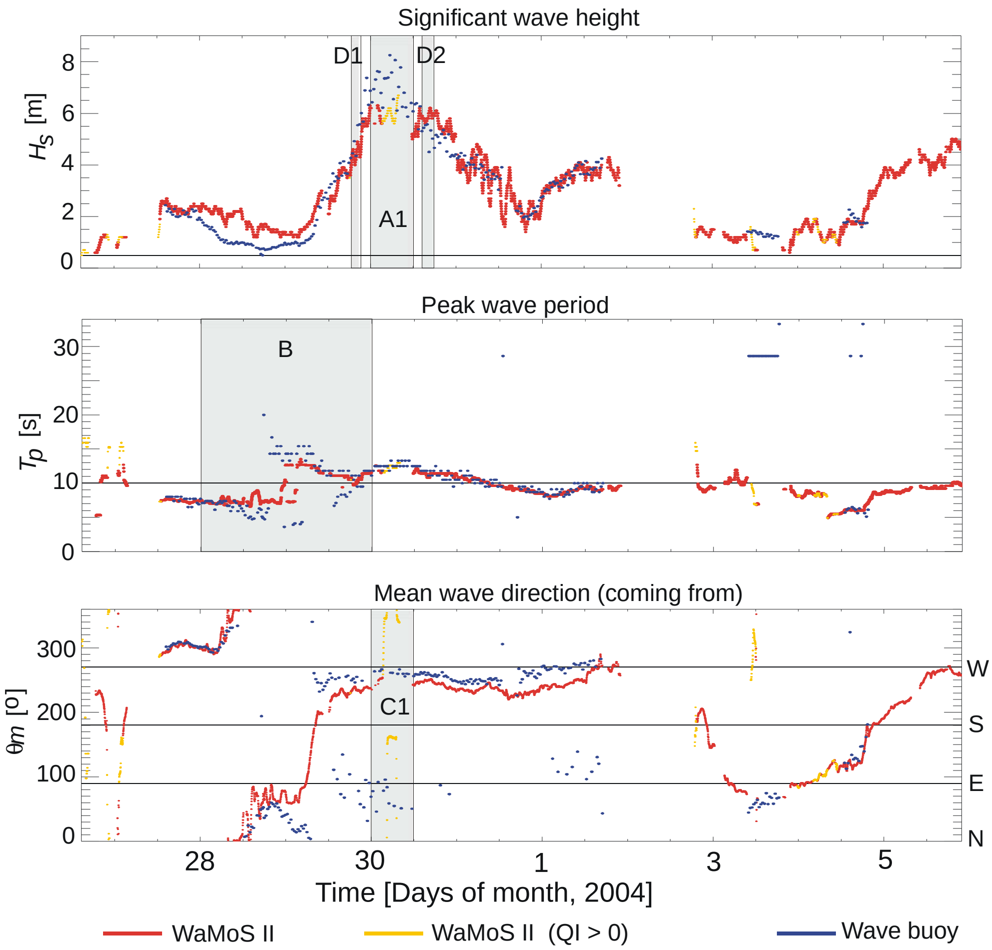

Fig. 5: Wave parameters as measured onboard CFAV Quest from January 26, 14:36 to February 5, 2004, 21:51, by WaMoS II (red and yellow) and the wave buoy (blue)

From January 28 to mid-morning on January 29, the quality of the WaMoS II is good but the *Hs* measured by WaMoS II is higher than that reported from the wave buoy. Fig. 6 shows the positions of WaMoS II and the wave buoy for this period. The figure shows the Quest's course during the trial Q279 (blue lines) and the locations of the free floating wave buoy (green lines). The red dots indicate the position of the CFAV Quest at specific times and the yellow dots the position of the wave buoy at specific times. The two sensors were generally within about 2.5 nautical miles of each other. There are one or two exceptions to this especially around 18:00 on the 28th where the separation reaches over 5 nautical miles.

It is hard to say if the separation of the sensors has any effect on the results for this period. Clearly WaMoS II is indicating

a) higher wave heights (especially in the first part of the period when the wave heights are quite small),
b) a more consistent peak wave period and ordered change from a wind wave to a swell wave, and
c) consistent with that, a more ordered change in the mean wave direction.

The small differences between the sensors for this period are probably caused by a combination of factors, some of which may be:

- Separation of the sensors at one time over 5 nautical miles.
- Large spatial sampling for WaMoS II as opposed to the point source for the buoy leading to a limitation of buoy to recognize general sea conditions as opposed to those existing at a point.
- Limitation of WaMoS II to measure accurately
- Significant wave height (*Hs*) less than 0.5m.

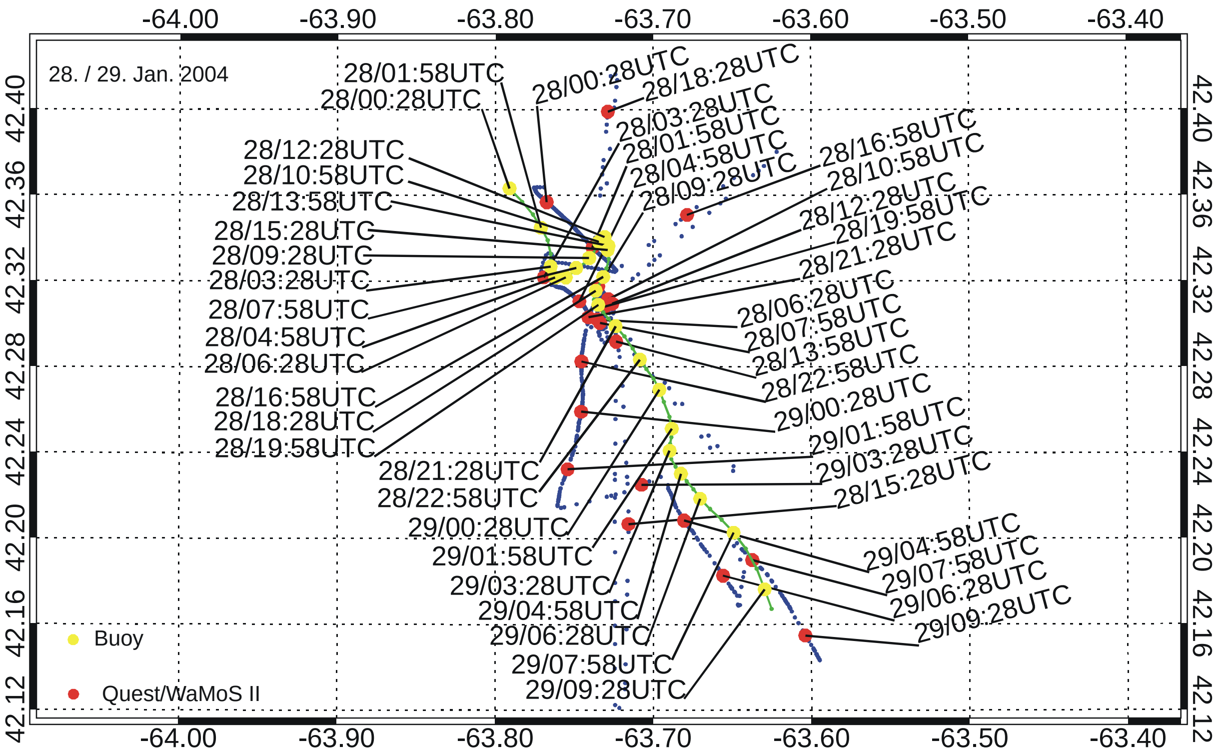

Fig. 6: Position of the CFAV Quest/ WaMoS II (red, blue) and the wave buoy (yellow, green) for January 28 to midday of January 29, 2004.

The two sections marked D1 and D2 in Fig. 5 are discussed later in Section 4.1 where the frequency spectra and the frequency-direction spectra are shown in detail.

A good agreement between the WaMoS II and the wave buoy is also visible for the peak wave period (*Tp*) (Fig. 5, middle panel). Only from January 28 to 30 can deviations be seen. At this time the sea state consists of two wave systems; a wind sea with a period of about 7 seconds, and a swell with a period of about 13 seconds. The figure shows that each sensor seemed to have identified a different wave system as the dominant one. This specific time period is marked and discussed in detail in Fig. 8.

On February, 3, the wave buoy measured wave periods of about 30 seconds. This seems to be unrealistic with respect to previous and succeeding measurements.

In the lower panel of Fig. 5, the mean wave direction θm is displayed. Both data sets show good agreement. Some deviations between the buoy and the WaMoS II are recognizable, especially during the period identified as C1 when the missing ship's speed and heading data input to WaMoS II was not available.

In Fig. 7 the *Hs* data from the WaMoS II are plotted against the *Hs* data from the wave buoy. The black and green data points indicate wave data with QI = 0, while data points when QI > 0 are in red. The green data points refer to data acquired in the period of January 28 until 29, when the buoy and the WaMoS II were located several kilometres apart. The dashed line indicates the ideal regression line, while the red line refers to the regression obtained for all data points (N=232), the blue line to the regression obtained for all data points with QI =0 (N=214) and the green line to all data points with QI=0 (N=147) when buoy and WaMoS II were close to together.

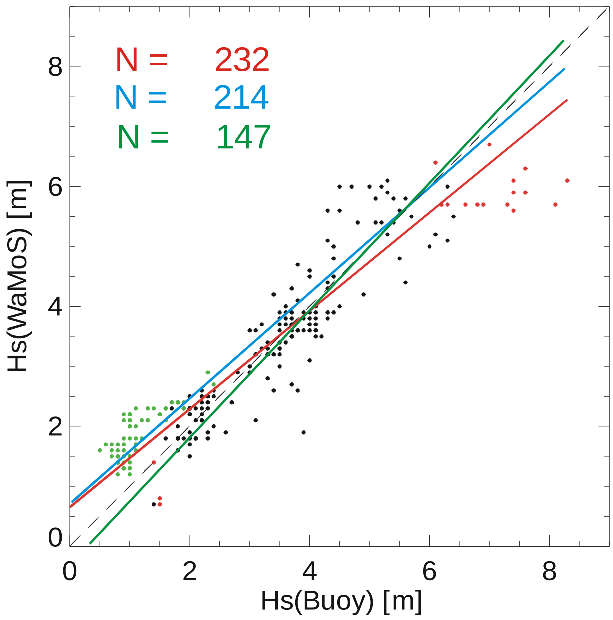

Fig. 7: Correlation of the significant wave height *Hs* between the WaMoS II and wave buoy measurements.

Table 2: Results of the comparison of *Hs* between the WaMoS II and the wave buoy

Parameter	Symbol	All data points (red, black, green points with red line)	All QI=0 (black, green points with blue line)	QI=0 (black points only with green line)
Number of data points	N	232	214	147
Correlation coefficient	r	0.94	0.93	0.91
Offset of the regression	a	0.65	0.54	-0.23
Slope of regression	b	0.82	0.88	1.06
Bias		0.11	0.21	-0.02
Root mean square error	RMS	0.69	0.61	0.52
Relative error	Rel	0.47	0.49	0.15

Fig. 8 zooms in on section B of Fig. 5, showing the time period from January 28 to 30. This figure shows the peak wave periods from the WaMoS II (red dots) and from the wave buoy (blue dots).

Around the 29th we see that a wind sea of approximately 7s is giving way to a swell of approximately 13s. In this time frame both the WaMoS II and the wave buoy oscillate between the two systems until early on the 29th when the swell starts to dominate. During this time period the wave buoy and the WaMoS II do not agree very well. It is suggested that this may be caused wholly or partly by their physical separation of over 6 kilometres (see Fig. 6).

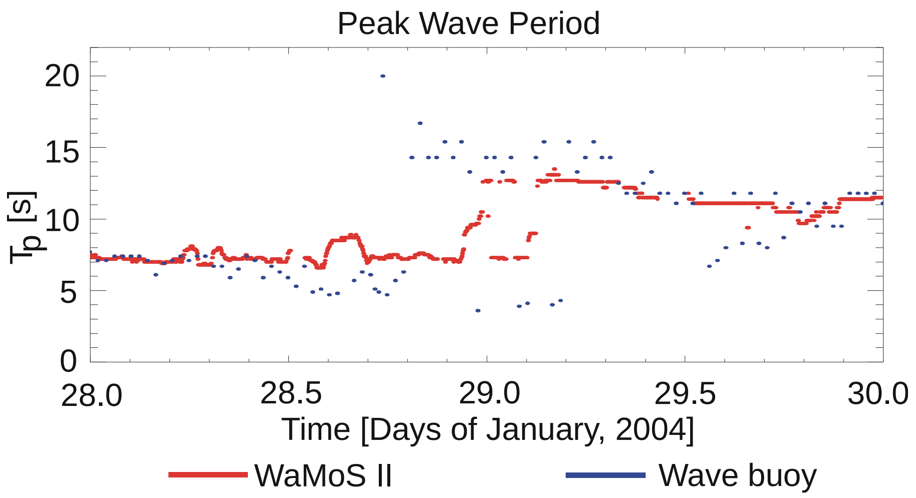

Fig. 8: Section B of the peak wave period as measured onboard CFAV Quest from January 28 to 30, by WaMoS II and the wave buoy

The correlation of the peak period *Tp* between the WaMoS II and the buoy is shown in Fig. 9; *Tp* data from WaMoS II are plotted against the *Tp* data from the wave buoy. The black and pink data points indicate the whole time period of the trial, while the pink data points refer to data acquired in the period of January 28 until 30, when the wave buoy and the WaMoS II measured different dominant systems (see Fig. 8).
The ideal regression line is indicated by the dashed line. The pink line refers to the regression obtained for all data points (N = 224), and the yellow line refers to the regression obtained for the black data points only (N = 132) without the time period of January 28 until 30 when WaMoS II and the wave buoy measured different dominant wave periods.

This comparison shows that when a sea state has a clear definition between wind and swell the results compare very favourably.

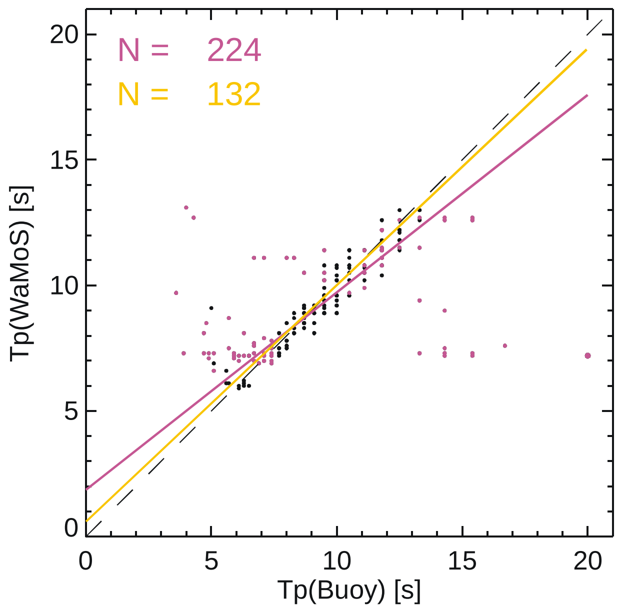

Fig. 9: Correlation of the peak wave period *Tp* between WaMoS II and wave buoy measurements

Table 3: Results of the comparison of *Tp* between the WaMoS II and the wave buoy

Parameter	Symbol	All data points (black & pink points with pink line)	Selection of data points (black data points only with yellow line)
Number of data points	N	224	132
Correlation coefficient	r	0.59	0.96
Offset of the regression	a	1.86	0.41
Slope of regression	b	0.79	0.94
Bias		-0.18	-0.15
Root mean square error	RMS	2.29	0.55
Relative error	Rel	0.31	0.06

4.2. Frequency spectra *S(f)* and Frequency-direction spectra *E(f,θ)*

As part of the comparison between the WaMoS II and the wave buoy, the one dimensional frequency spectra *S(f)* and the two dimensional frequency-direction spectra *E(f,θ)* are analysed. Two time periods are chosen, and these are marked in Fig. 5 as D1 and D2.

The first period, (Fig. 5, section D1) on January 29, 2004 from 19:02 to 20:58 represents a growing sea sate. The second time period (Fig. 5, section D2) on January 30, 2004 from 17:02 to 18:59 is selected because it represents the maximum values obtained for the significant wave height *Hs* during the trials. The following data are all 30 minute mean values.

Fig. 10 shows several WaMoS II 1-dimensional frequency spectra *S(f)* and corresponding values for *Hs* from the period D1 (Fig. 5). In the upper panel values of *Hs* that are measured every 2 minutes are marked as red dots. The grey vertical lines indicate the times where comparisons between the WaMoS II and buoy spectra are given (see Fig. 11 and Fig. 13). The coloured lines refer to changes in the 1-dimensional frequency spectra shown in Fig. 12 which represent a sea with an increasing *Hs* from 4 to 5m.

In the lower panel of this figure the WaMoS II 1-dimensional frequency spectra are plotted over the same time period. The wave energy density reaches a value of *S(f)* = 40 m²/ Hz. It becomes clearly apparent that the significant wave height and the energy density shown in the frequency spectra are associated with each other, as the *Hs* and the wave energy increase simultaneously.

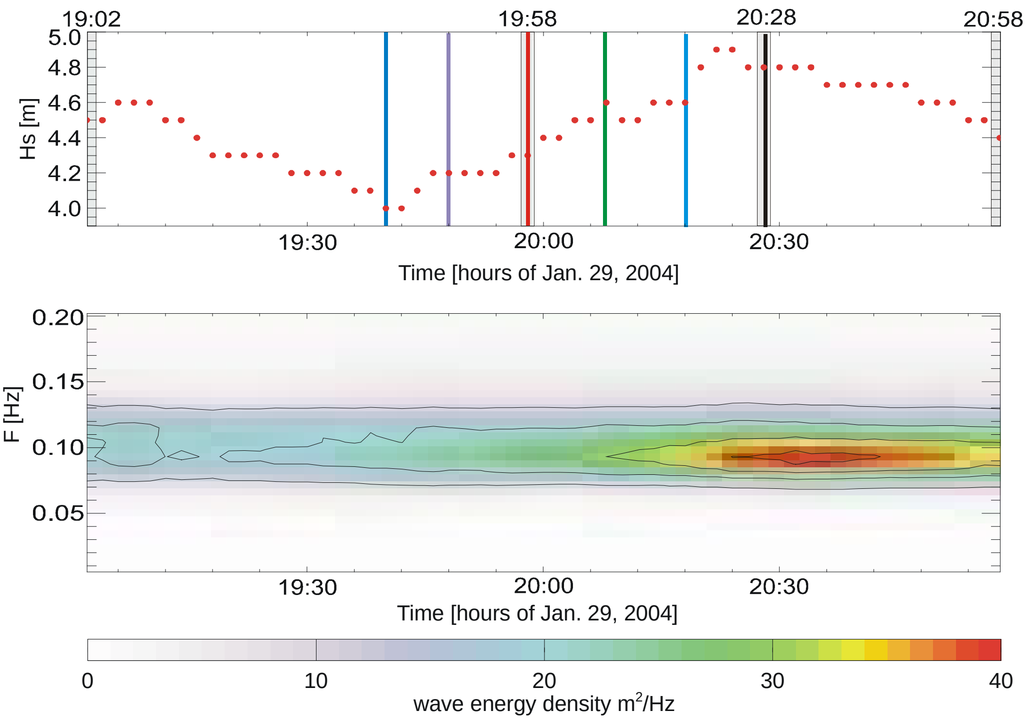

Fig. 10: The significant wave height *Hs* and 1-d frequency spectra of WaMoS II as function of time during the period January 29, 2004, 19:02 until 20:58.
The colour scaling corresponds to the wave energy.

Figures 11a to 11d compare the frequency spectra of the WaMoS II and the wave buoy for the period of January 29, 2004, 19:02 to 20:58. The red line represents the WaMoS II data and the blue line the wave buoy data. There is no wave buoy frequency spectrum available for the January 29, 2004, 19:30 time frame.

The two 1-dimensional frequency spectra show good agreement in their general shape but differ in their magnitude. The smoother curve of the WaMoS II data may be due to both the greater spatial resolution of the measurement, and the larger number of spectra that are available for the temporal averaging.

The 1D-spectra of the wave buoy in this series from 19:02 to 20:58 indicate an unknown artefact. For time periods 19:02 and 19:58 they indicate no energy at all in frequencies less than about 0.065/ 0.07 Hz (Fig. 11a and 11b); yet on the other hand for time periods 20:28 and 20:58 they show an artificial peak in the low frequency range less than 0.05 Hz (Fig. 11c and 11d). The source of this artefact is unknown. The analysis of the *Hs* however may be affected by this artefact. The values of *Hs* between WaMoS II and buoy are quite closely correlated when the artefact is absent (Fig. 11a and 11b) but are not so close when the artefact is present (Fig. 11c and 11d). In the latter case the *Hs* indicated by the buoy increases by over 1m.

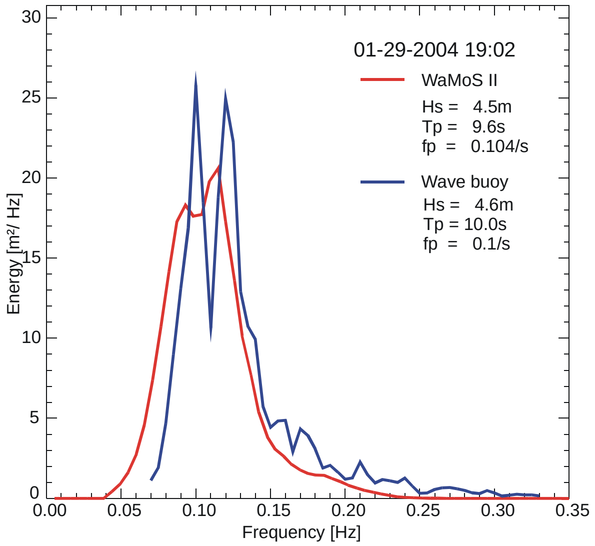

Fig. 11a: Frequency spectra *S(f)* of WaMoS II and the wave buoy on January 29, 2004, 19:02.

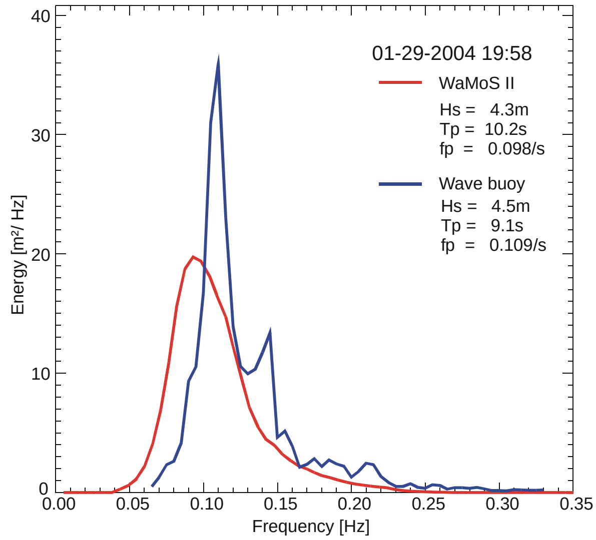

Fig. 11b: Frequency spectra *S(f)* of WaMoS II and the wave buoy on January, 29 2004, 19:58.

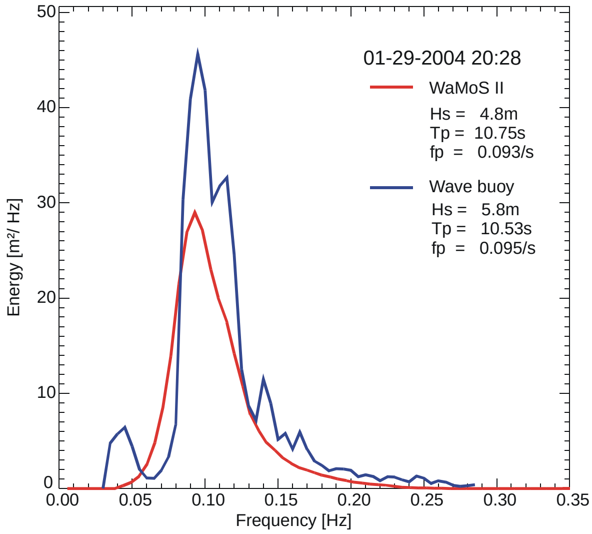

Fig. 11c: Frequency spectra *S(f)* of WaMoS II and the wave buoy on January 29, 2004, 20:28.

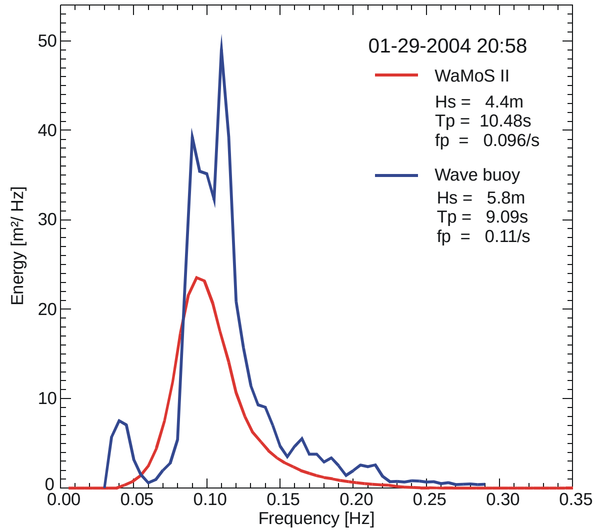

Fig. 11d: Frequency spectra *S(f)* of WaMoS II and the wave buoy on January 29, 2004, 20:58.

Fig. 11: Frequency spectra *S(f)* of WaMoS II and wave buoy during the period January 29, 2004, 19:02 to 20:58. The red line indicates WaMoS II and the blue line the wave buoy.

Fig. 12 from WaMoS II data, shows the evolution of the frequency spectrum between 19:40 – 20:28 on January 29th. The different colours refer to the different times of data acquisition. The spectra exhibit a typical evolution of a growing sea. As time elapses the spectra become higher and narrower and shift towards the lower frequencies.

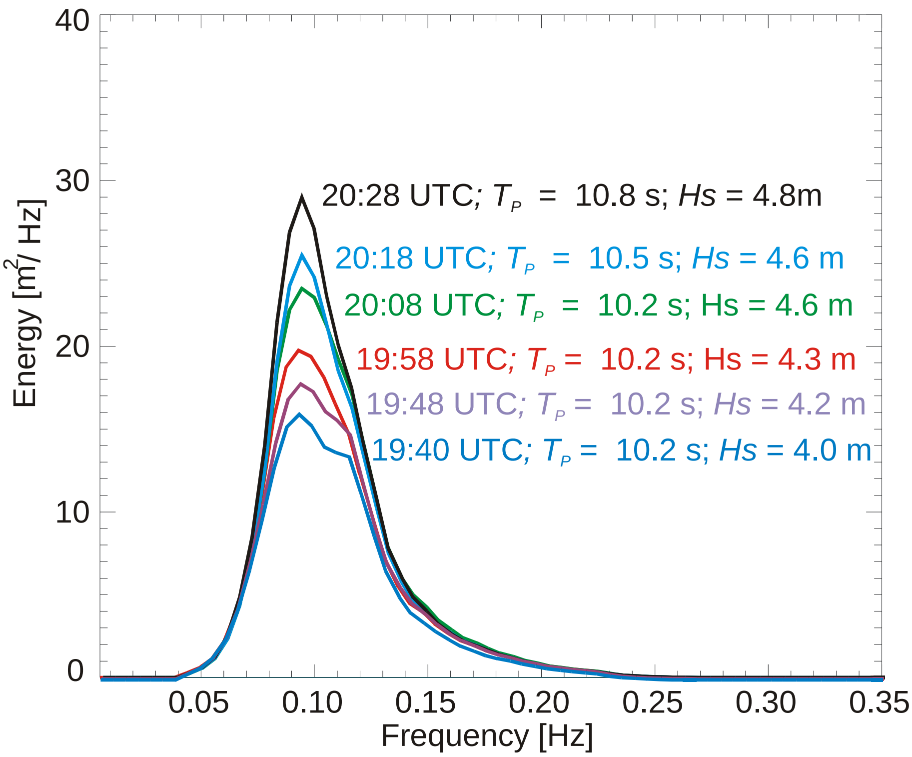

Fig. 12: Frequency spectra *S(f)* as obtained by WaMoS II during the January 29, 2004, 19:40 to 20:28.

Fig. 13a-d shows a comparison of the frequency-direction spectra $E(f,\theta)$ for the same time period of January 29, 2004, 19:02 to 20:58. In the upper panel the wave energy of the WaMoS II is plotted, the lower panel shows the corresponding wave energy from the wave buoy. The two spectra (19:02 (a) and 19:58 (b)) agree very well. The directionality of the energy distribution with higher frequencies (about 0.12 Hz, wind sea) for waves coming from 270° and lower frequencies (about 0.9 Hz; swell) for waves coming from 210° can be observed in both the WaMoS II and buoy spectra. Small differences can be explained by the different measuring techniques.

However the spectra in Fig. 13c and Fig. 13d differ quite significantly. While the WaMoS II shows similar spectra to the previous ones, the buoy detects a different wave system with waves coming from nearly all directions. Sometimes the buoy seems to generate erroneous directional spectra with energy spread across all headings. These erroneous buoy spectra occur vary rarely and other times more frequently. The reason for this is unknown.
Nevertheless both sensors sense waves in the same frequency range (0.8-0.12 Hz). At this time the wave buoy records a slightly higher *Hs* than the WaMoS II. Note that during this time the values of *Tp* and θm reported from the buoy varied significantly between successive measurements (see also Fig. 5 and Fig. 8).

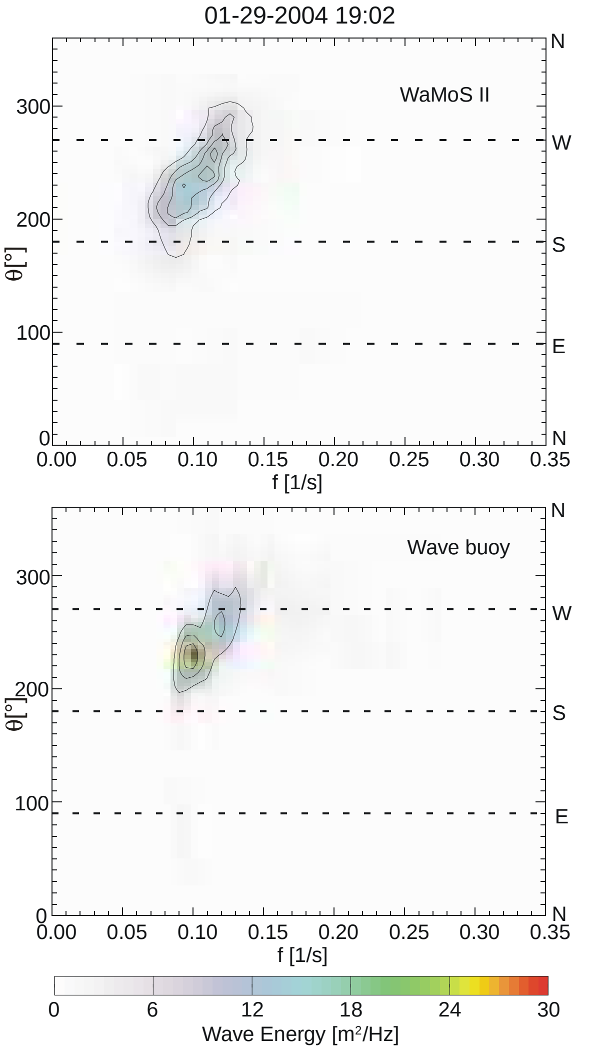

Fig. 13a: Directional spectra $E(f,\theta)$ of WaMoS II and wave buoy on January 29, 2004, 19:02.

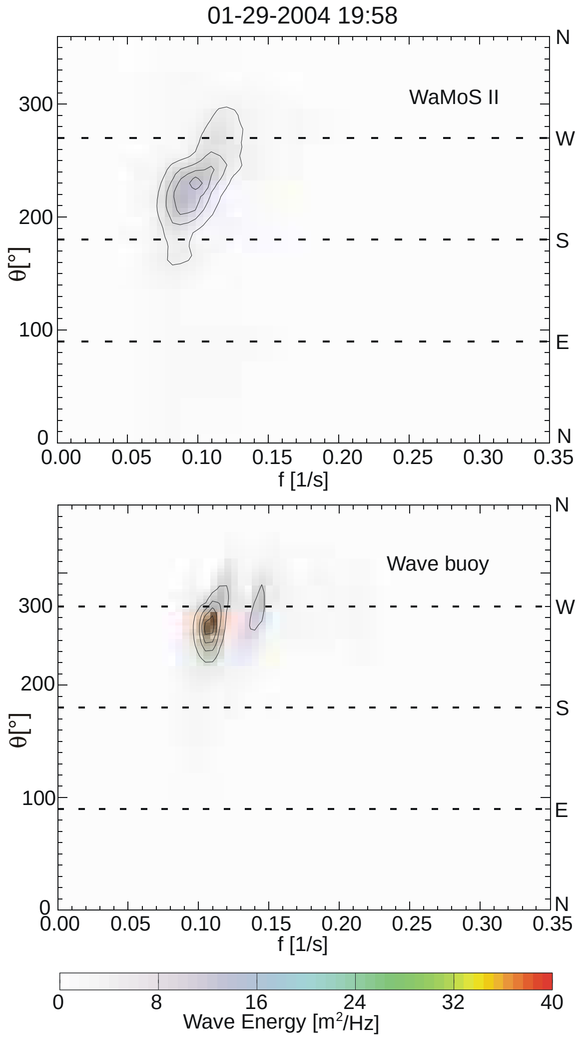

Fig. 13b: Directional spectra $E(f,\theta)$ of WaMoS II and wave buoy on January 29, 2004, 19:58.

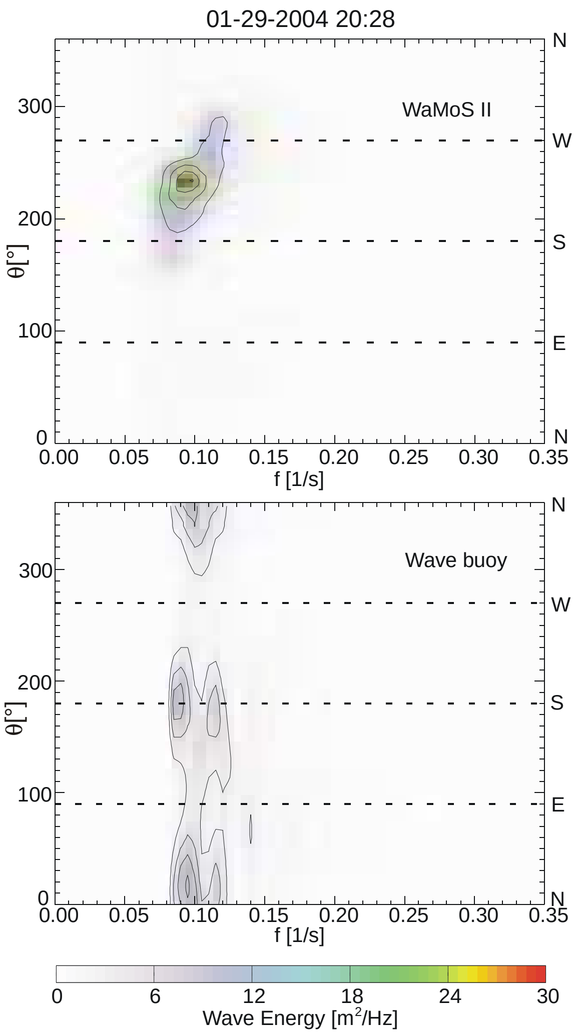

Fig. 13c: Directional spectra *E(f,θ)* of WaMoS II and wave buoy on January 29, 2004, 20:28.

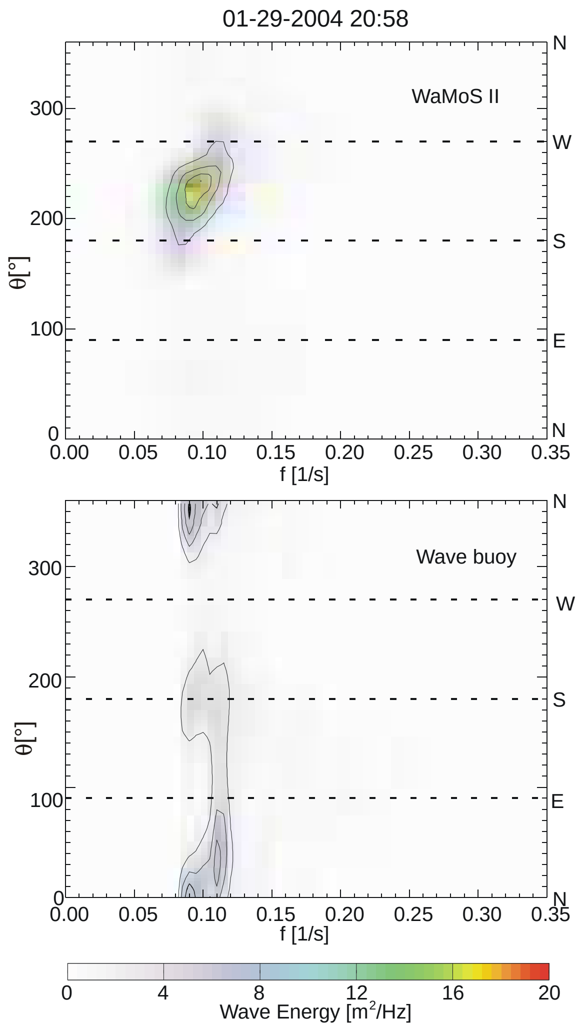

Fig. 13d: Directional spectra *E(f,θ)* of WaMoS II and wave buoy on January 29, 2004, 20:58.

Fig. 13: Directional spectra *E(f,θ)* of WaMoS II and wave buoy during the period January 29, 2004, 19:02 until 20:58. The colour scaling corresponds to the wave energy.

In Fig. 14 the significant wave height, *Hs,* and a series of 1-dimensional frequency spectra, *S(f),* of the WaMoS II are plotted for the second time period (Fig. 5, section D2). In the upper panel five grey blocks are displayed which mark the specific times for the data comparisons of the 1-dimensional frequency spectra (Fig. 15) and frequency-direction spectra (Fig. 16).

The upper panel shows the significant wave height on January 30, 2004 from 17:02 to 18:59. They varied between 5.8 m and 6.1 m. In the lower panel of this figure a series of the WaMoS II 1-dimensional frequency spectra is plotted over the same time period. The wave energy density is up to a maximum of *S(f)* = 60 m²/ Hz. The wave heights are almost constant over this period, and the wave energy density is quite uniform for the whole period.

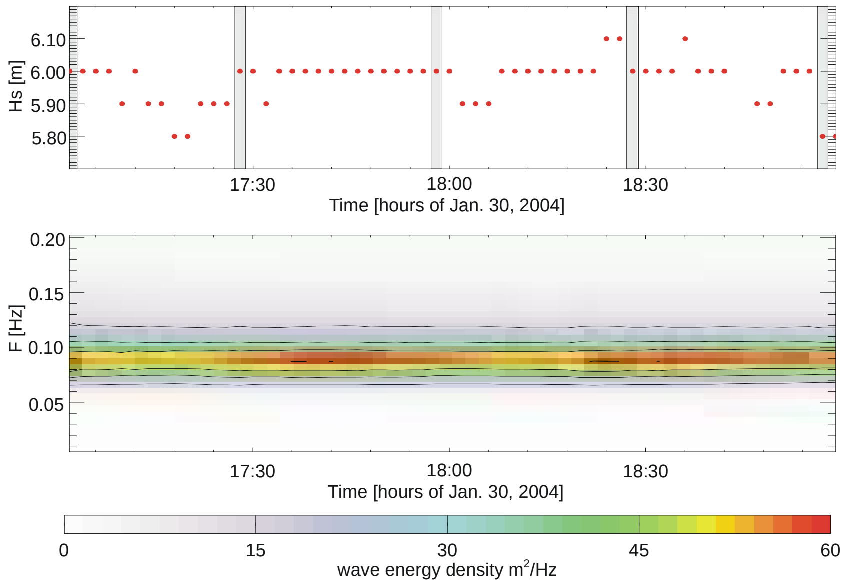

Fig. 14: The significant wave height and a series of 1-d frequency spectra of WaMoS II from January 30, 2004 -17:02 to 18:59. The colour scaling corresponds to the wave energy.

In Fig. 15a-e, the 1-dimensional frequency spectra *S(f)* are plotted for January 30, 2004 from 17:02 to 18:57. The red line describes the WaMoS II spectra and the blue line the buoy spectra.

The 1D-spectra show a good agreement in their general shape and magnitude, except in Fig. 15c. In this series from 17:02 to 18:57 the 1-dimensional frequency spectra of the wave buoy do not show the unknown artefact in the low frequency range (see Fig. 11). However except for the time period 17:02 where the energy starts at a frequency range about 0.05 Hz (Fig. 15a) the remaining spectra indicate no energy at all in frequencies less than about 0.07 Hz (Fig. 15b and 15e). It is not clear why this is so.
In the higher frequency ranges however, both spectra show similar energy/ frequency values.
Note that the *Hs* from the wave buoy during this period is lower than the *Hs* from the WaMoS II (see Fig. 5, section D2).

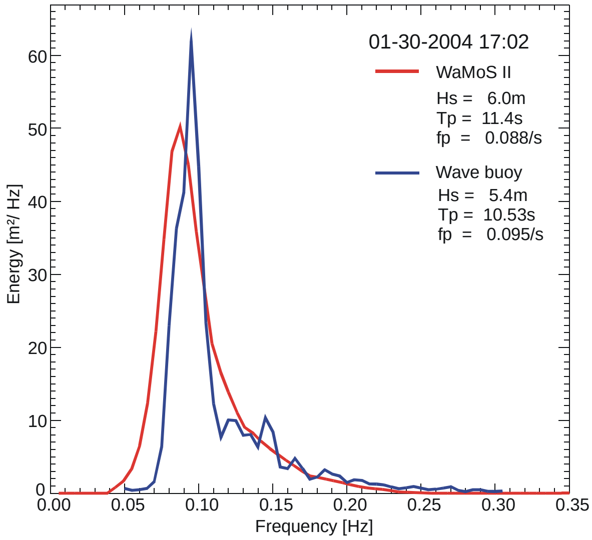

Fig. 15a: Frequency spectra *S(f)* of WaMoS II and the wave buoy on January 30, 2004, 17:02.

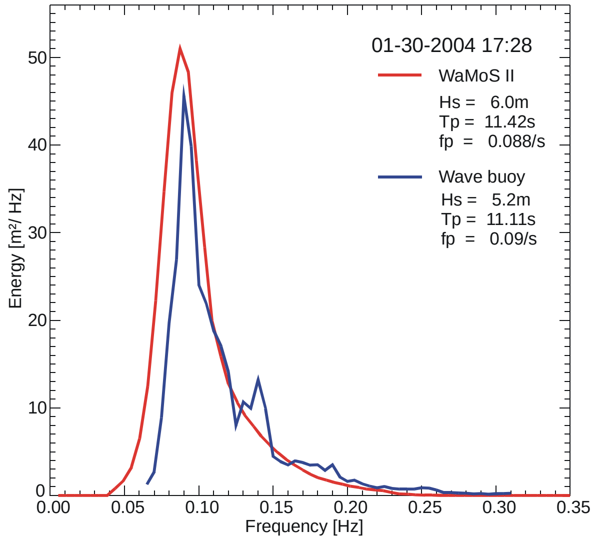

Fig. 15b: Frequency spectra *S(f)* of WaMoS II and the wave buoy on January 30, 2004, 17:28.

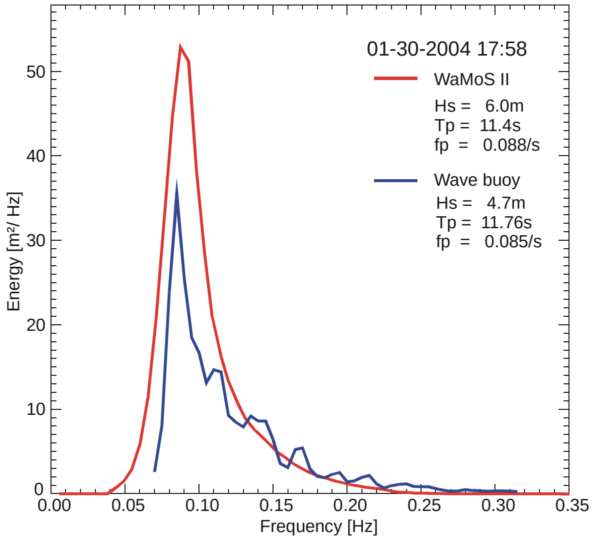

Fig. 15c: Frequency spectra *S(f)* of WaMoS II and the wave buoy on January 30, 2004, 17:58.

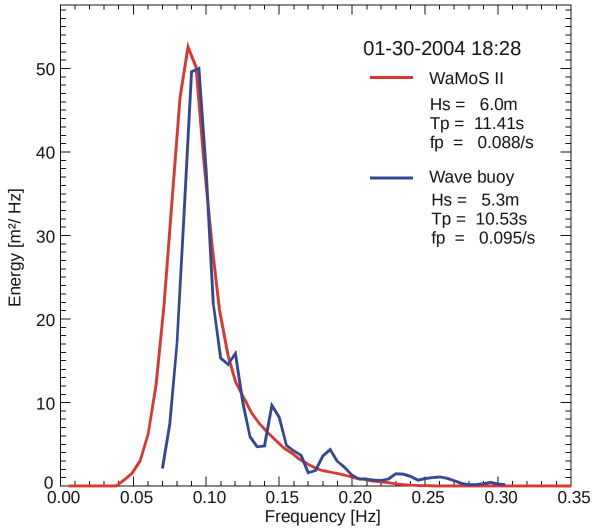

Fig. 15d: Frequency spectra *S(f)* of WaMoS II and the wave buoy on January 30, 2004, 18:28.

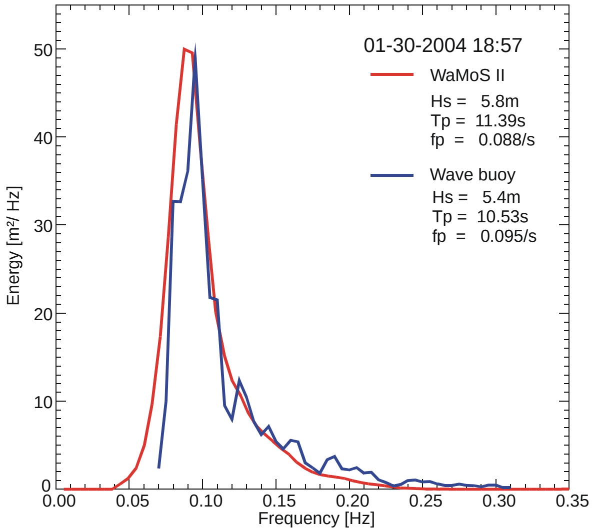

Fig. 15e: Frequency spectra *S(f)* of WaMoS II and the wave buoy on January, 30, 2004, 18:57.

Fig. 15: Frequency spectra *S(f)* of WaMoS II and the wave buoy on January 30, 2004, from 17:02 to 18:57. The red line represents WaMoS II and the blue line the wave buoy.

Fig. 16a-e shows the comparisons of the 2-dimensional spectra *E(f,θ)* during the period January 30, 2004, 17:02 to 18:57. In the upper panel of this figure the wave energy of the WaMoS II is plotted, in the lower panel the energy of the wave buoy is displayed.

The frequency-direction spectra *E(f,θ)* differ in the main wave direction by approximately 40 degrees in all panels. The reason for this disagreement can be related to the different wave spreading that is visible in the 2-dimensional spectra. Whether this difference in directional information is related to the different measuring principles or to the different locations of the WaMoS II and the wave buoy (see Fig. 17) is not clear.

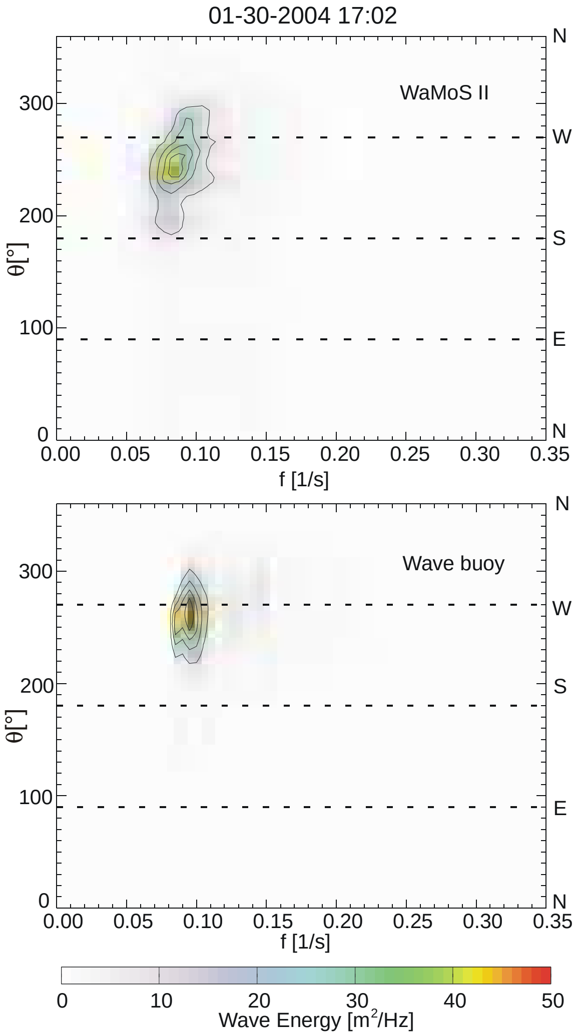

Fig. 16a: Directional spectra *E(f,θ)* of WaMoS II and wave buoy on January 30, 2004, 17:02.

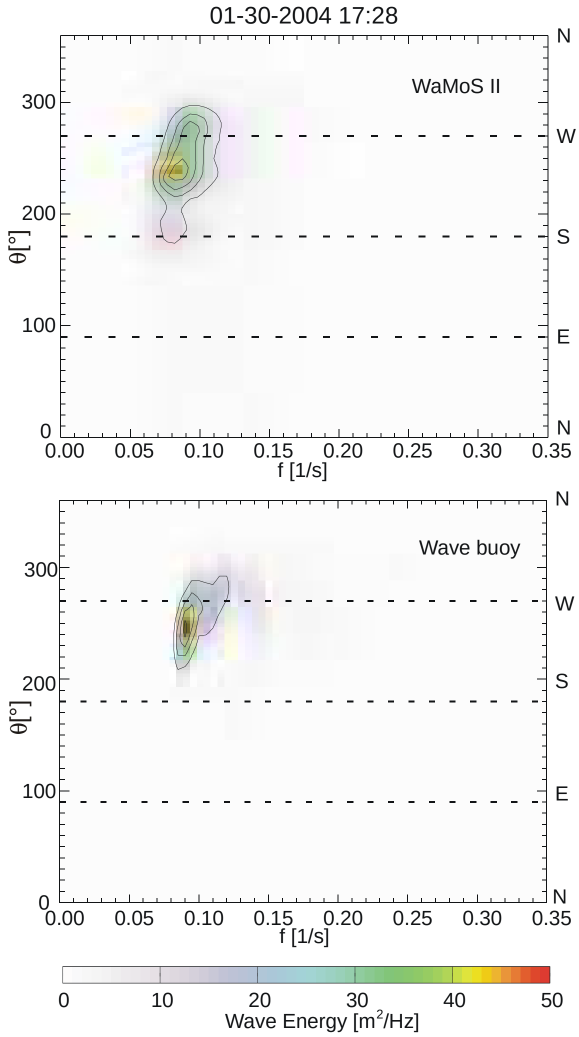

Fig. 16b: Directional spectra *E(f,θ)* of WaMoS II and wave buoy on January 30, 2004, 17:28.

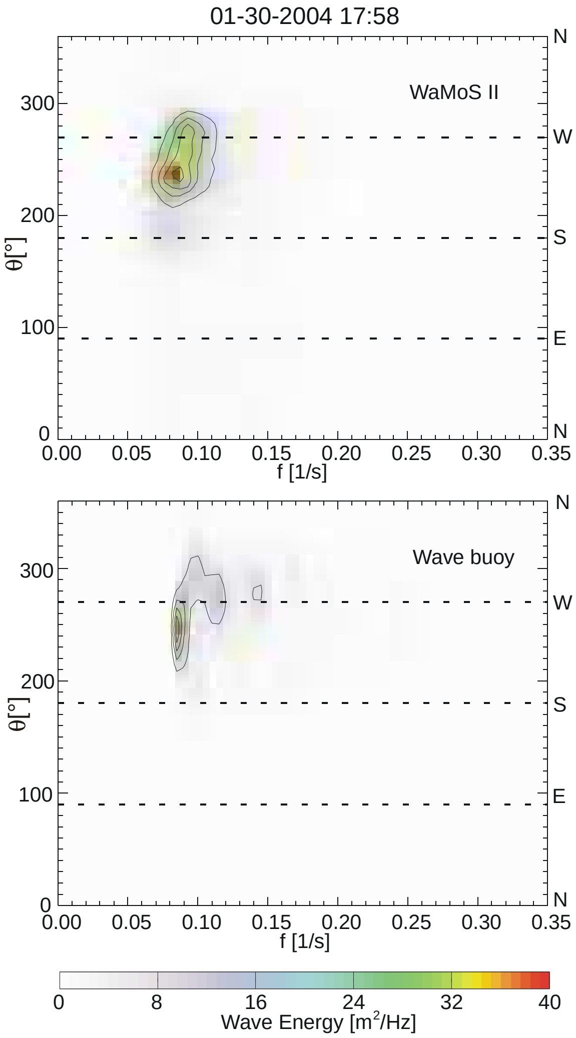

Fig. 16c: Directional spectra *E(f,θ)* of WaMoS II and wave buoy on January 30, 2004, 17:58.

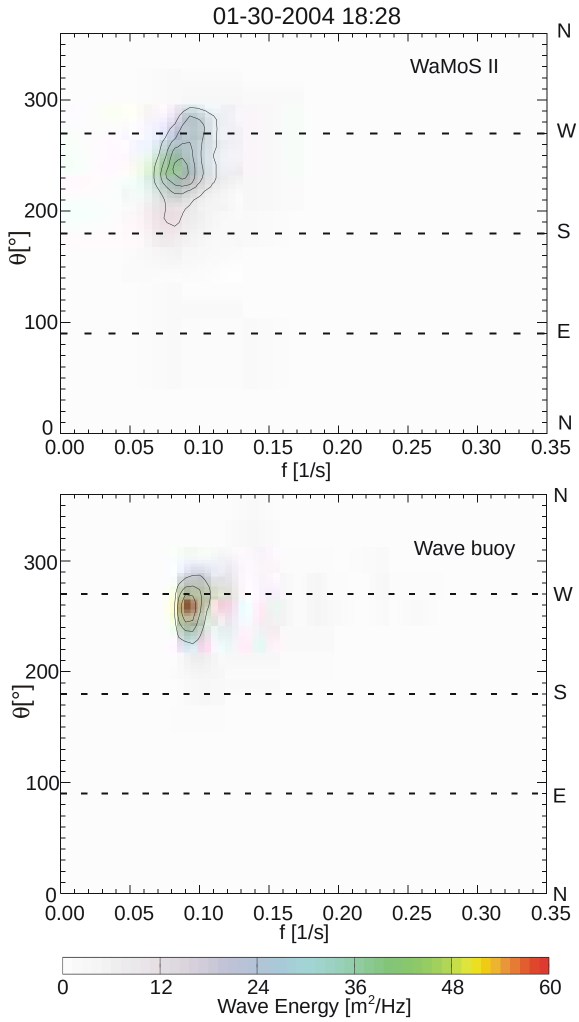

Fig. 16d: Directional spectra *E(f,θ)* of WaMoS II and wave buoy on January 30, 2004, 18:28.

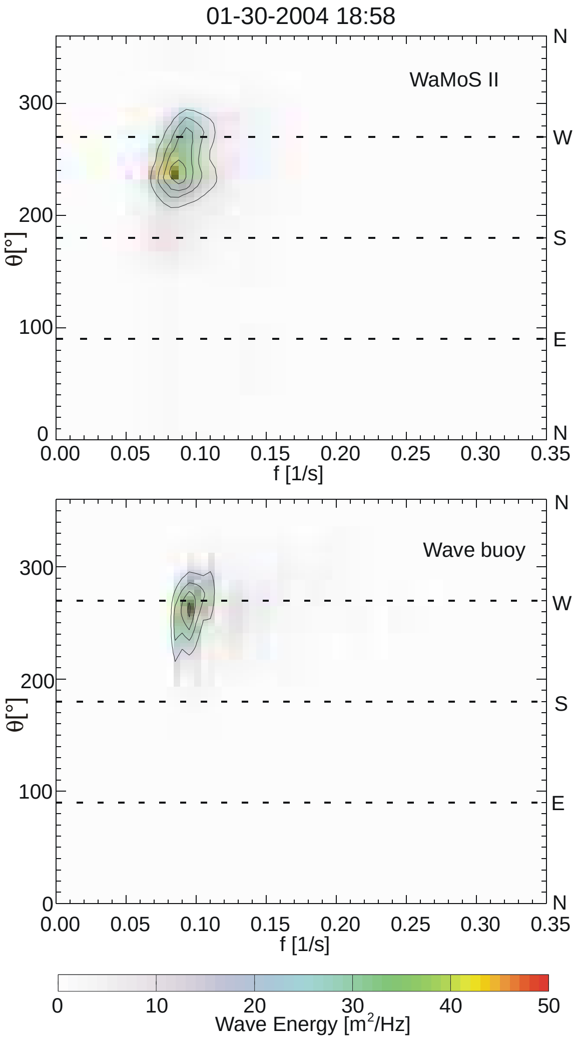

Fig. 16e: Directional spectra $E(f,\theta)$ of WaMoS II and wave buoy on January 30, 2004, 18:58 .

Fig. 16: Directional spectra $E(f,\theta)$ of WaMoS II and the wave buoy on January 30, 2004, from 17:02 to 18:58. The colour scaling corresponds to the wave energy.

In Fig. 17 the Quest's course during the trial Q279 (blue lines) and the locations of the free floating wave buoy (green lines) are shown. The red dots indicate the position of the CFAV Quest at specific times and the yellow dots the position of the wave buoy at specific times.

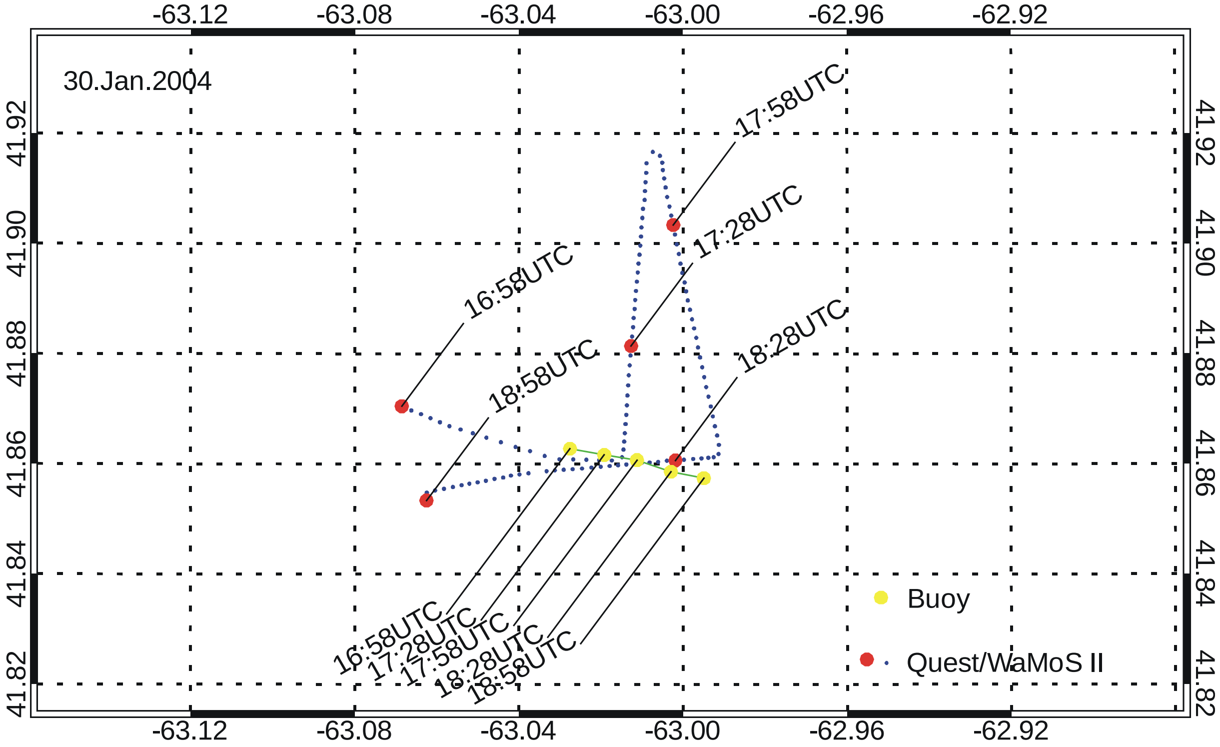

Fig. 17: Map with position of the CFAV Quest and the wave buoy on January 30, 2004.

5. Summary

This report details some of the wave data comparisons between an operational WaMoS II wave radar mounted on the CFAV Quest and a free floating TRIAXYS™ directional wave buoy. The data were taken from a trial in late January/ early February 2004 off the Scotian Shelf in deep water.

In general the comparisons between the two measuring devices are very good. If one takes the measurement parameters of significant wave height and peak period as indicators of sea state then the two devices show excellent agreement. The regression curves for *Hs* and *Tp* for the whole period show correlation coefficients and biases of 94% and 11% and 96% and 15% respectively. If the sea surface is truly homogenous and the buoy location is in the same area as that measured by WaMoS II, then one might expect similar results for all measured parameters and spectra. By and large these are the findings of this report.

However, there is a significant difference in what each device is measuring. Typically, with the Quest travelling at 6 knots, over a 30 minute averaging period, the WaMoS II samples approximately 7 sq km of the ocean surface. The WaMoS II data thus incorporates a large spatial average. On the other hand the TRIAXYS™ directional wave buoy is measuring data from a single point (with some drift over the 30 minute period). Also, even in deep water, the sea surface is not uniform either spatially or temporally. So we would expect to see some differences in the data between the two sensors. Most noticeable are the differences in the overall shape of the 1-dimensional frequency spectra and the 2-dimensional frequency/ direction spectra. As one might expect, the spatial averaging of the WaMoS II provides a smoother 1-D spectra in all cases, leading to a more consistent picture of the sea state. Fig. 15, which shows the classic growth of a sea state over time, is an example of the advantages of dealing with a spatially averaged spectra.

Additionally the WaMoS II 2-D spectra are more consistent than those from the wave buoy. This is particularly evident in Fig. 13.

The WaMoS II has a unique facility, and that is a built-in quality control feature. For all input data that meets various predetermined criteria, a Quality Index of zero is assigned. For all other data where there are problems, the value of QI is greater than zero. This enables the reviewer to assess the reliability of certain data. In this report this facility has been very useful in determining the validity of certain data. When the WaMoS II is mounted on a ship, the ship speed and direction data are important parameters, without which the quality of the WaMoS II analysis is compromised.

Overall, the ability of the WaMoS II to provide reliable and consistent data has been proven again. The ease with which the system was set up, the accuracy of the analysed data and the consistency of the results show that the WaMoS II is a valuable alternative instrument that can be used with confidence for monitoring sea state either from a ship or from a fixed platform (land or sea based).

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This report details some of the wave data comparisons between an operational WaMoS II wave radar mounted on the CFAV QUEST and a free floating TRIAXYS directional wave buoy. The data were taken from a trial in late January/ early February 2004 off the Scotian Shelf in deep water. In general the comparisons between the two measuring devices was very good. If one takes the measurement parameters of significant wave height and peak period as indicators of sea state then the two devices showed excellent agreement in most conditions. If the sea surface is truly homogenous and the buoy location is in the same area as that measured by WaMoS II, then one might expect similar results for all measured parameters and spectra. By and large these were the findings of this report. However, there is a significant difference in what each device is measuring. Typically, with the Quest travelling at 6 knots, over a 30 minute averaging period, the WaMoS II samples approximately 7 sq km of the ocean surface. The WaMoS II data thus incorporates a large spatial average. On the other hand the TRIAXYS directional wave buoy is measuring data from a single point (with some drift over the 30 minute period). Even in deep water, the sea surface is not uniform either spatially or temporally,so we would expect to see some differences in the data between the two sensors. Most noticeable were the differences in the overall shape of the 1-dimensional frequency spectra and the 2-dimensional frequency/direction spectra in some instances.

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wave spectrum
directional spectrum

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